Earthquake-Induced Ground Failures in Tsunami Inundation Zones

by

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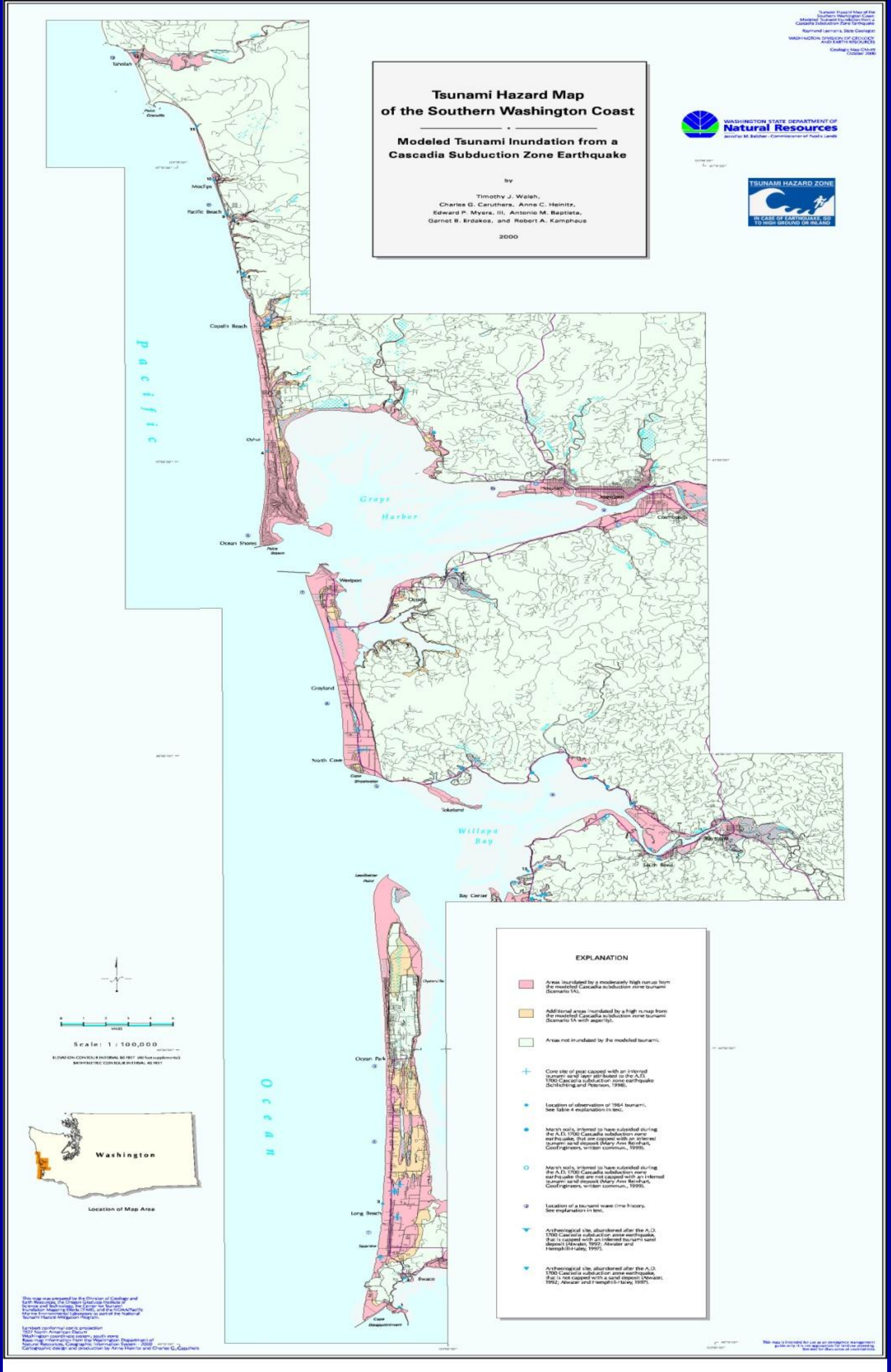
Areas affected by a tsunami from a Cascadia subduction zone earthquake would be subjected to strong ground shaking first. The response to the tsunami will depend on surviving the earthquake and navigating potential ground failures to evacuate to safety.



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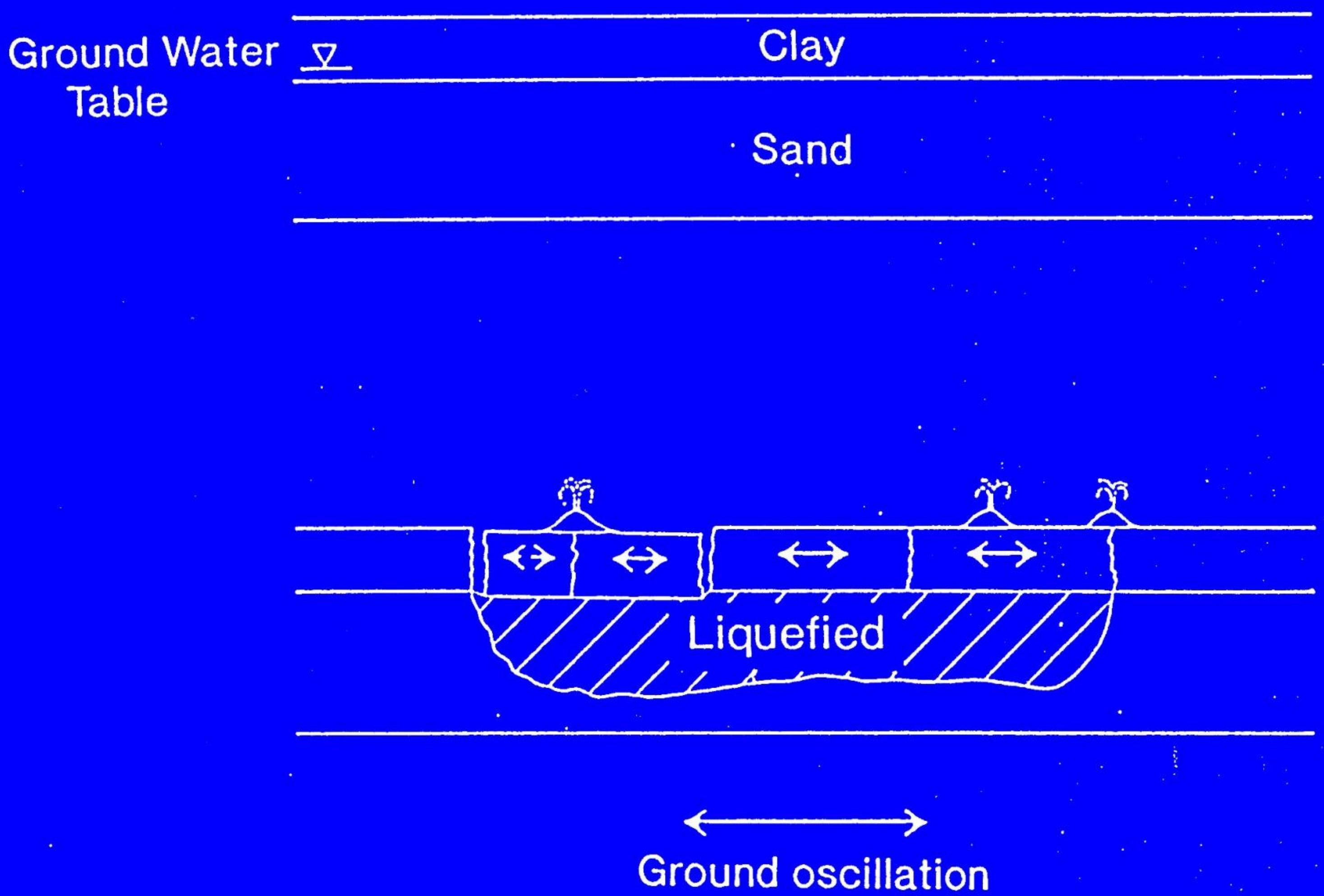
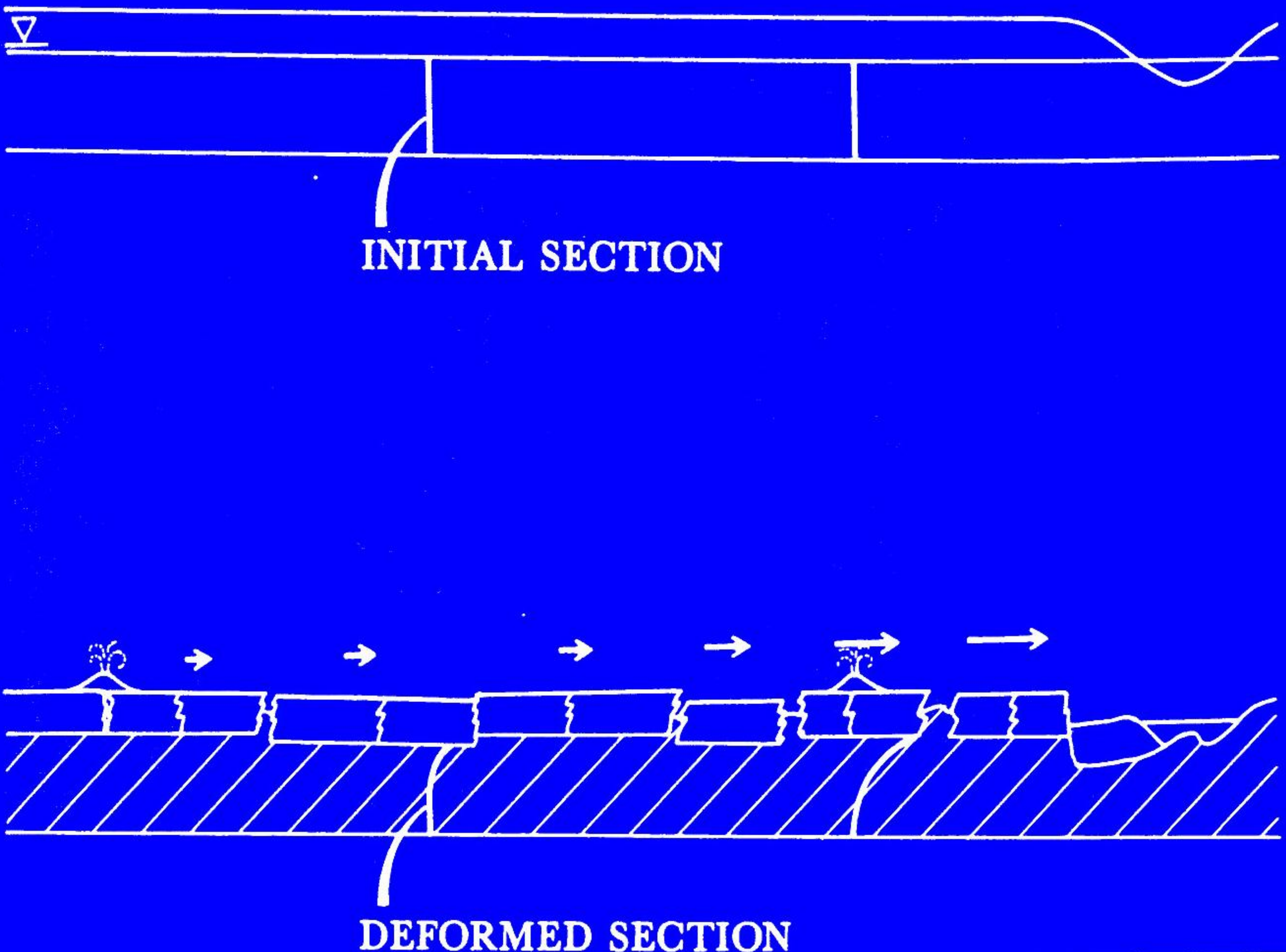
Strong ground shaking can cause liquefaction of saturated granular soils. This results in a loss of strength and potential ground failure on very low slopes.

Fissures and Sand Boils



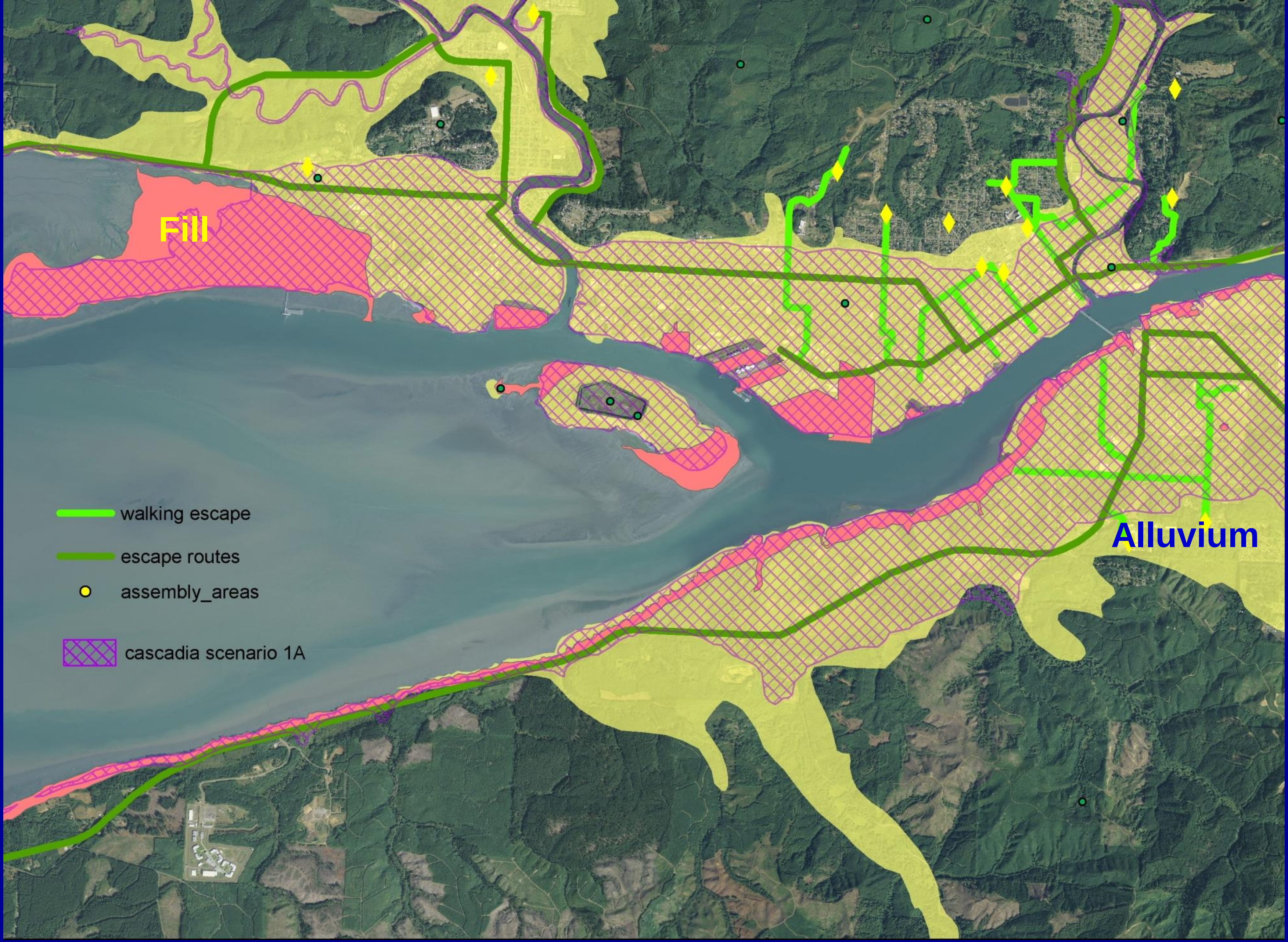
These sand blows occurred in Olympia during the 1965 earthquake

Cross-section of sand blows in Alaska caused by the 1964 earthquake

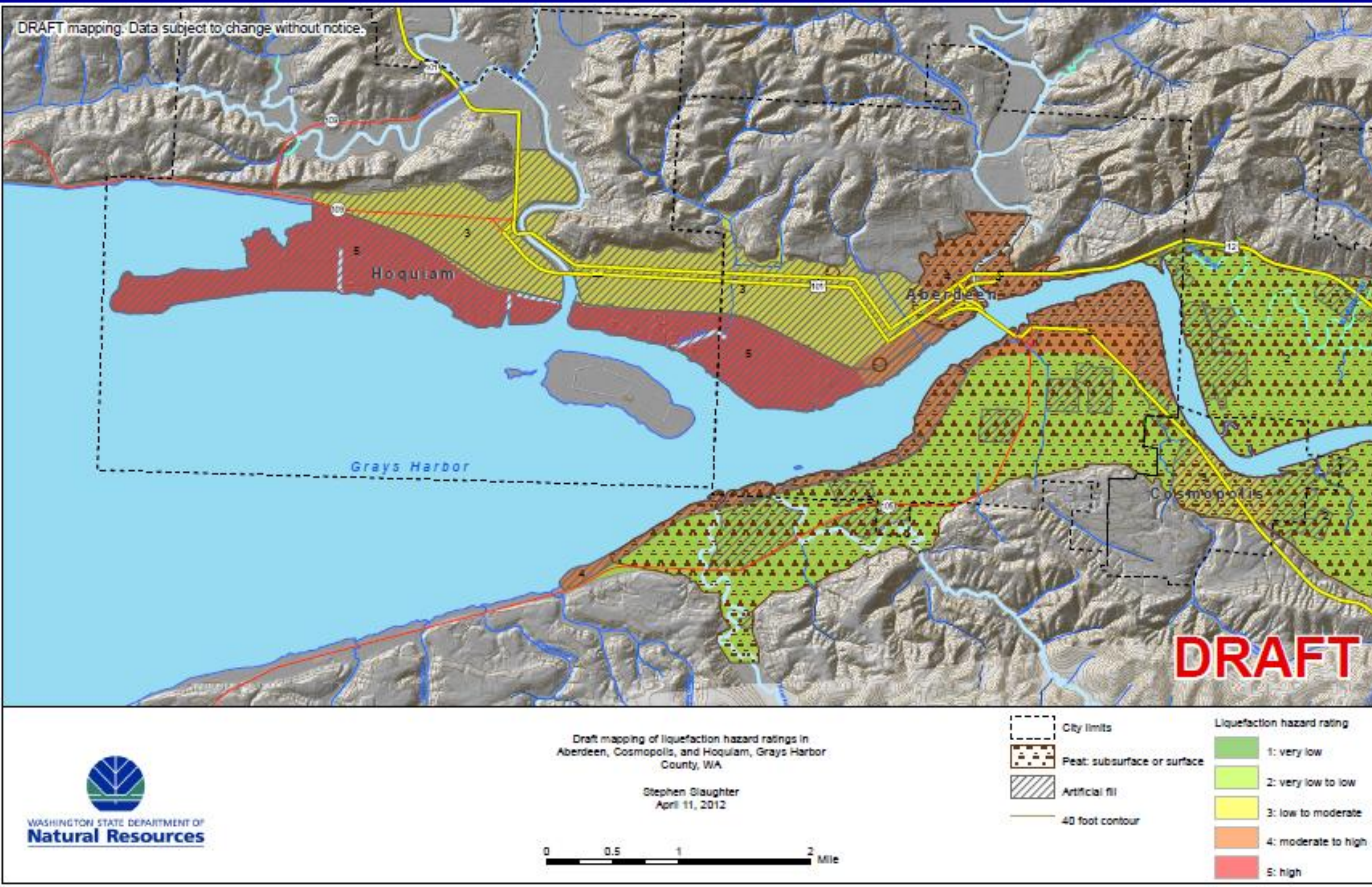

INITIAL SECTION
DEFORMED SECTION

Liquefaction-induced lateral spread on Deschutes Parkway in Olympia caused by the 1965 earthquake

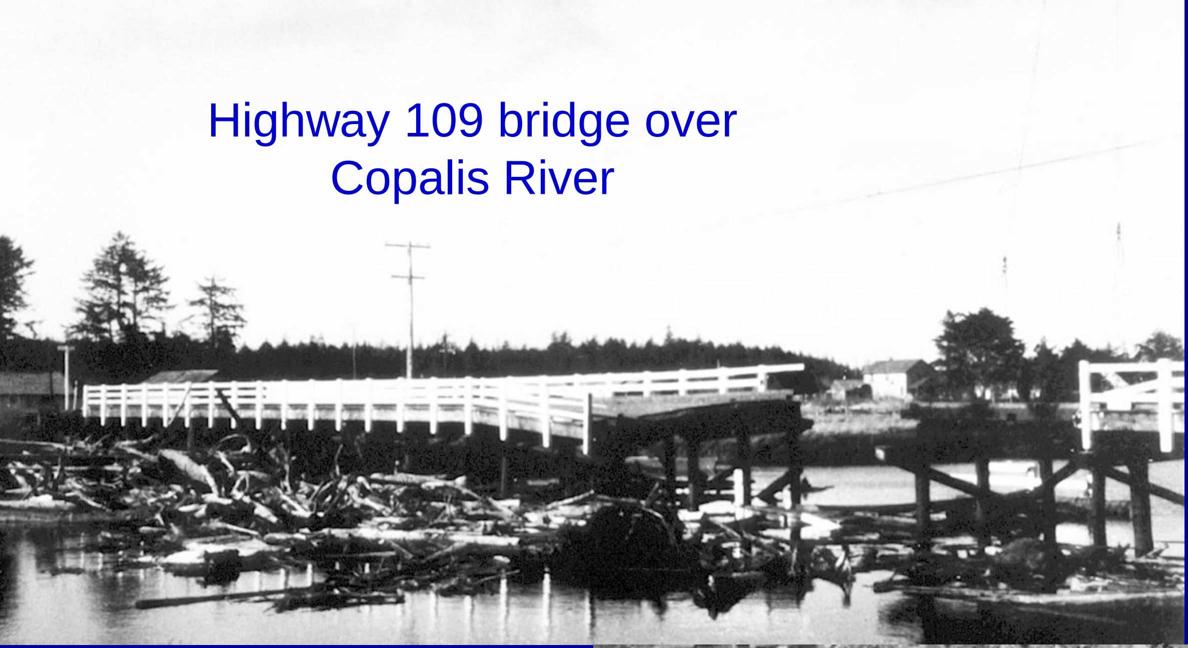
Liquefaction-induced lateral spread on Deschutes Parkway in Olympia caused by the 2001 earthquake



This map shows loose geologic units (color) with the inundation zone (hatching). Evacuation routes are in green. Assembly areas in yellow dots.



This map shows the liquefaction susceptibility with the inundation area overlain. Note that they are mostly coextensive. The program (WSLiq) makes conservative assumptions where there is no data, so this probably overestimates slightly.



Tsunami damage from the 1964 Alaska earthquake. The wave here was about 10-12 feet. Note that damage was from floating debris, not just water.

Strong ground shaking at the Port of Grays Harbor could cause *liquefaction* and ground failure, causing these logs to become entrained in the tsunami

Earthquake-induced landslides are also a problem.

Earthquake-Induced Landslides

Nisqually Earthquake, 2001

U.S. 101 Landslide


Cedar River Landslide


Capital Lake Landslide


Salmon Beach Landslide

This soil slip in Carkeek Park was triggered by the 1965 earthquake

This landslide in Edmonds was triggered by a major earthquake in 1965

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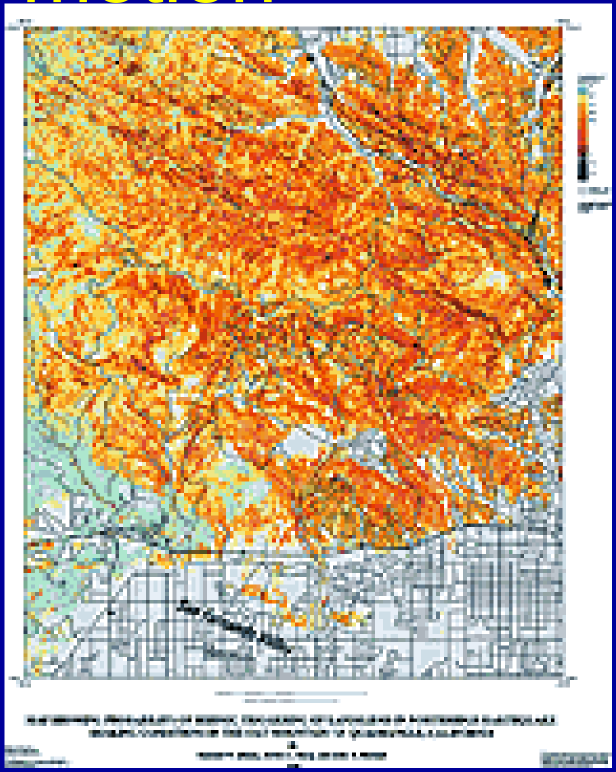
How do we approach a solution?

- Jibson and others modeled potential seismic-induced slope failure in California
- Critical acceleration – ground motion necessary to initiate failure.



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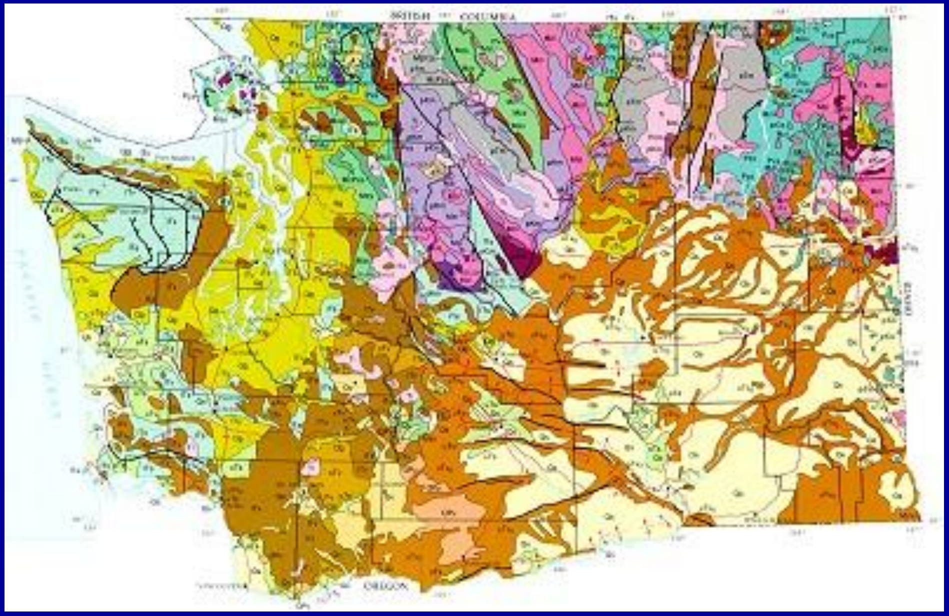
Modelbuilder on ArcGIS

- Simple, visual model
- Uses data in mxd
- Cell-by-cell calculations
- The best part - very little code writing!!!

What do we need?



- Geology
- Strength characteristics
- DEM
- Saturation
- Depth to failure plane

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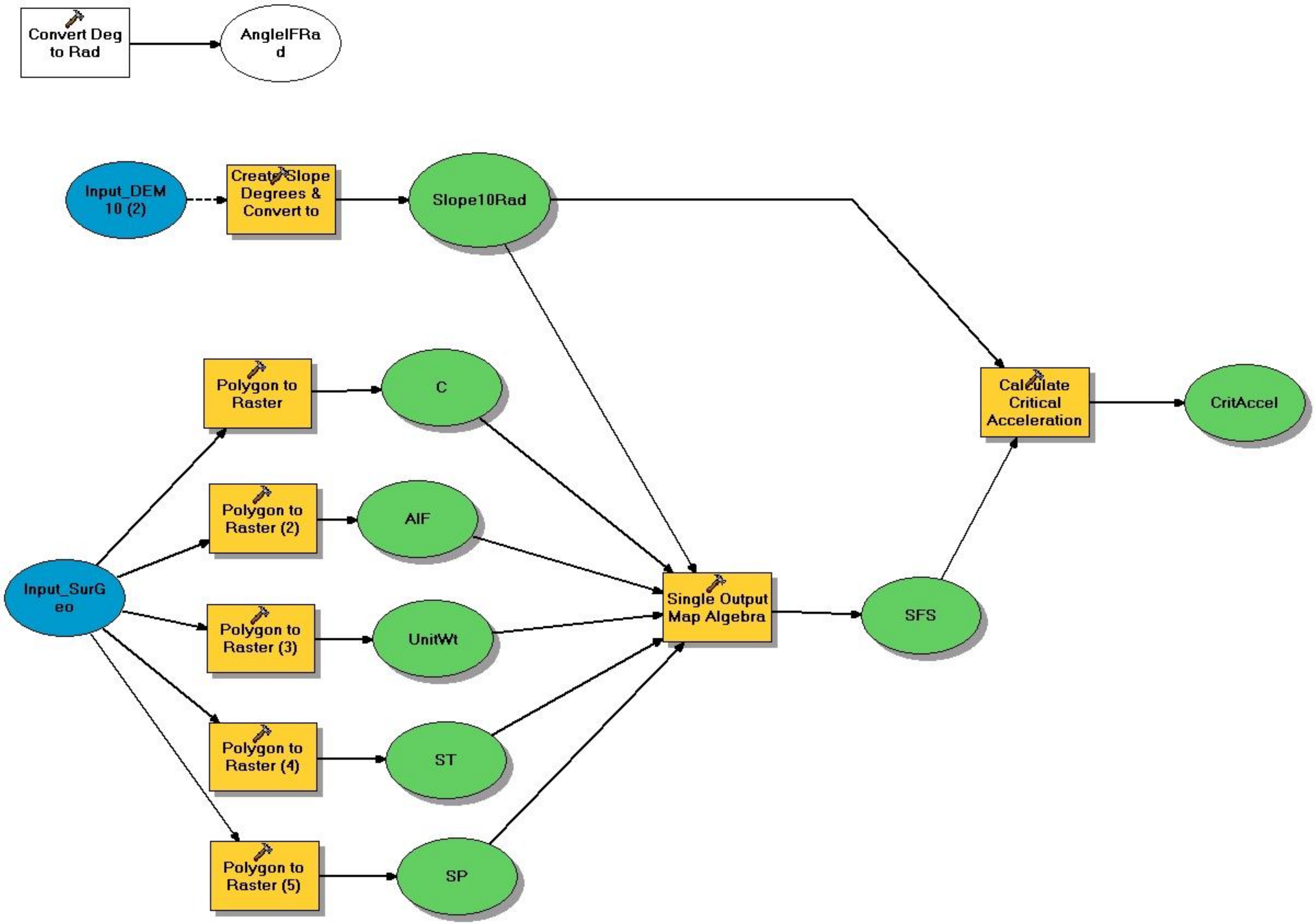
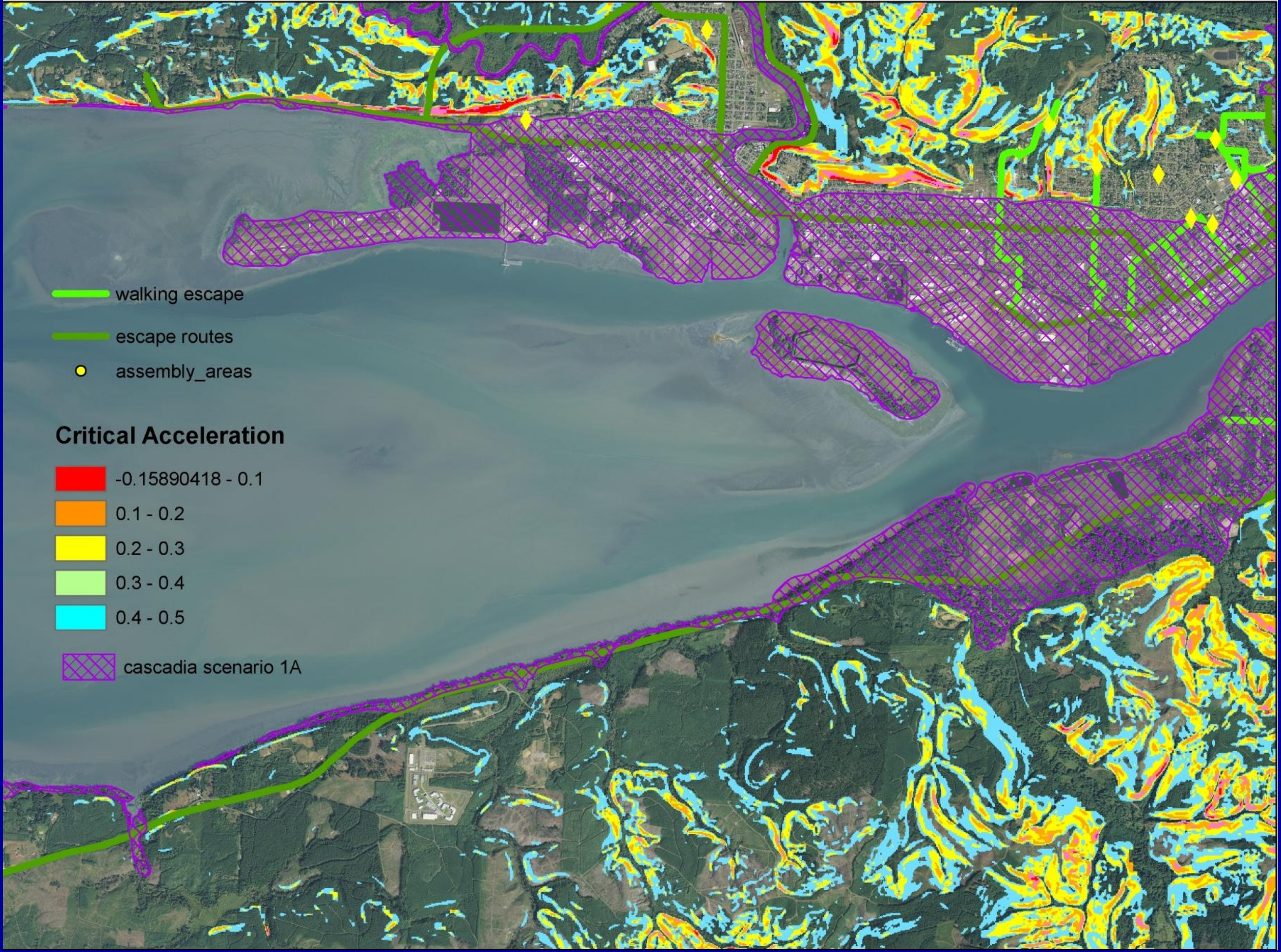
$$FS_S = \frac{c'}{\gamma t \sin\alpha} + \frac{\tan\varphi}{\tan\alpha} - \frac{m\gamma_W \tan\varphi}{\gamma \tan\alpha} \qquad \text{Eq. 1}$$

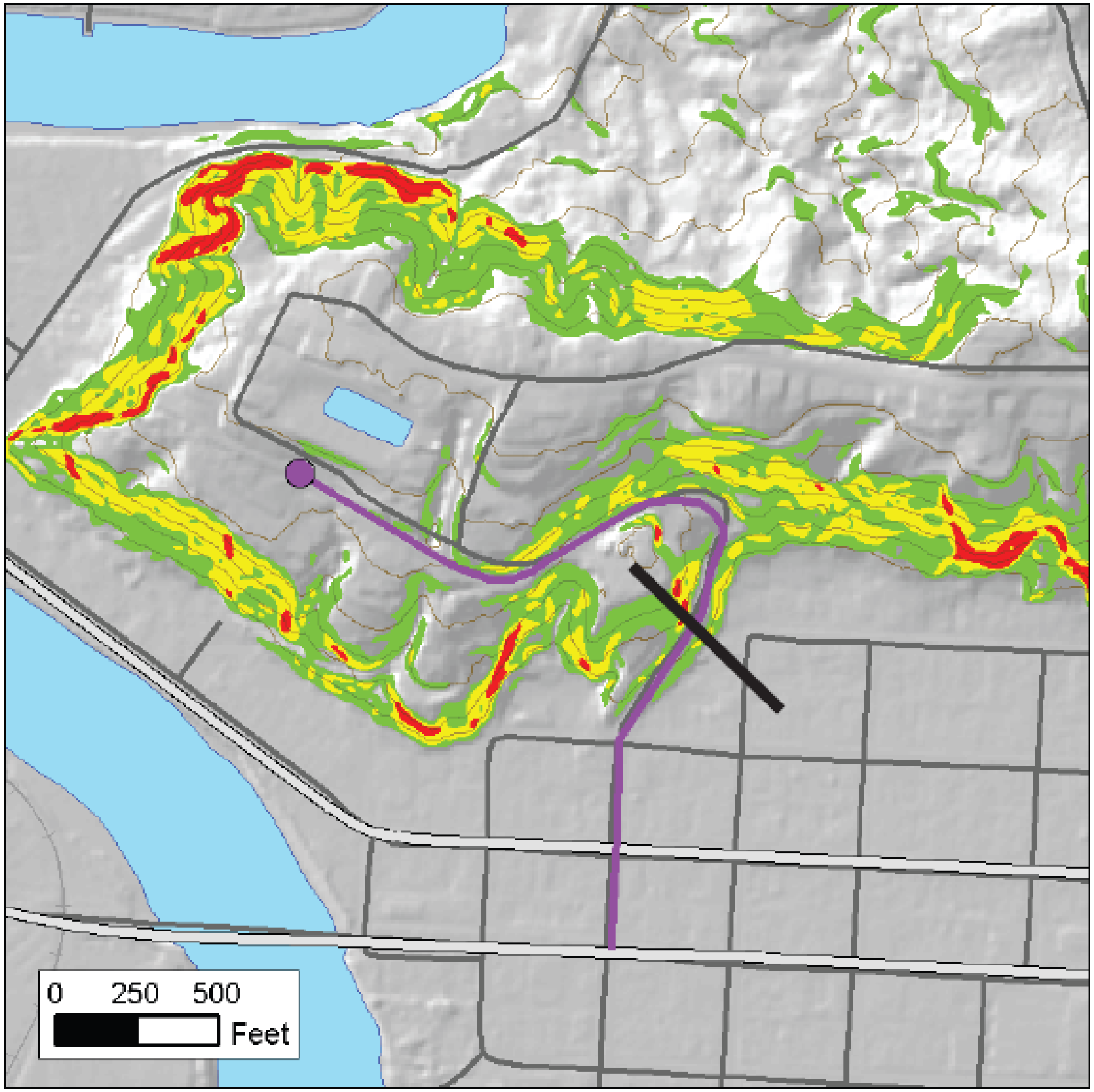
$$a_c = (FS_s - 1) g \sin\alpha \qquad \text{Eq. 2}$$


Convert Deg to Rad
AngleIFRad
Input_DEM 10 (2)
Create Slope Degrees & Convert to
Slope10Rad
Polygon to Raster
C
Polygon to Raster (2)
AIF
Input_SurGeo
Polygon to Raster (3)
UnitWt
Polygon to Raster (4)
ST
Polygon to Raster (5)
SP
Single Output Map Algebra
SFS
Calculate Critical Acceleration
CritAccel

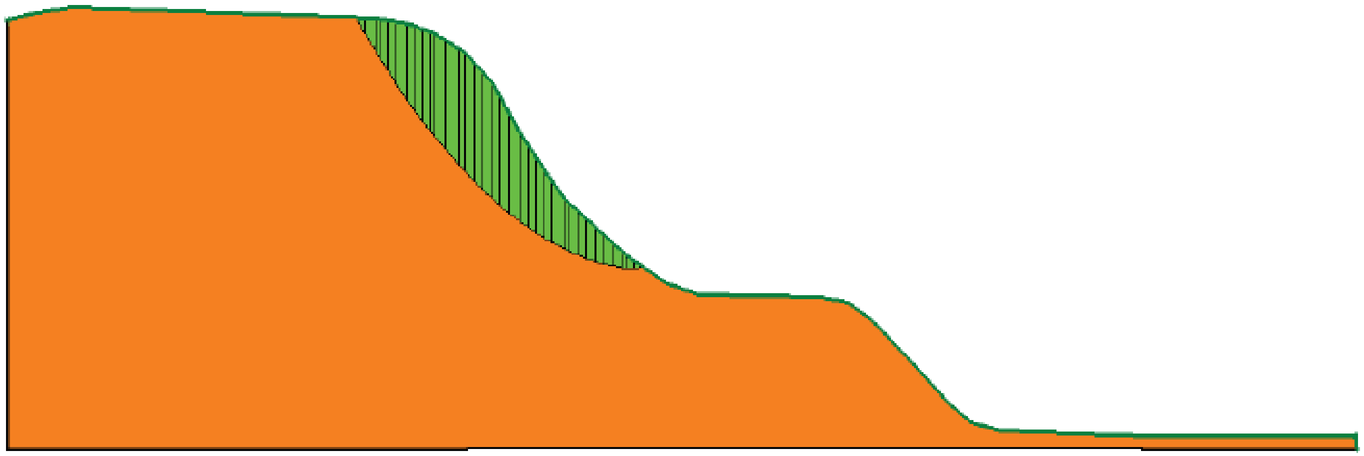


Areas susceptible to shallow, earthquake-induced landslides. Red areas require only relatively weak ground shaking, whereas the green areas require hard ground shaking. This is modeled with a water table 3 feet below ground surface.

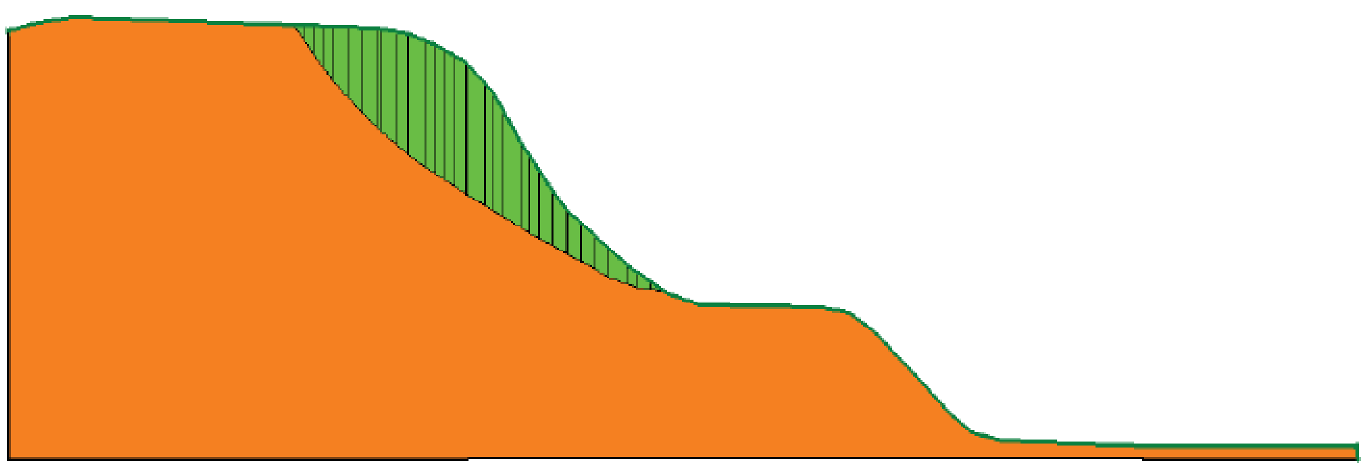
Figure X. Examples of SLOPE/W output. Upper cross-section depicts the static factor of safety for the evacuation route that ascends Beacon Hill. The green point illustrates the center of the rotation slip surface and the factor of safety. The lower cross-section depicts the factor of safety under a horizontal acceleration of 0.4 g. The map to the right is a topographic map of the area. The black line is the cross-section, purple is the evacuation route, and the red, yellow, and green identify critial acclerration zone of seismically-induced shallow landslide as high, medium, and low, respectively.



FS = 1.60



FS = 0.95



We analyzed the slope below the hospital along the lines shown in this photo for susceptibility to deep-seated landslides along a curved slide plane. A detailed analysis would require a lot of data collection, such as number, orientation, and spacing of fractures, orientation of bedding, and degree of water saturation.

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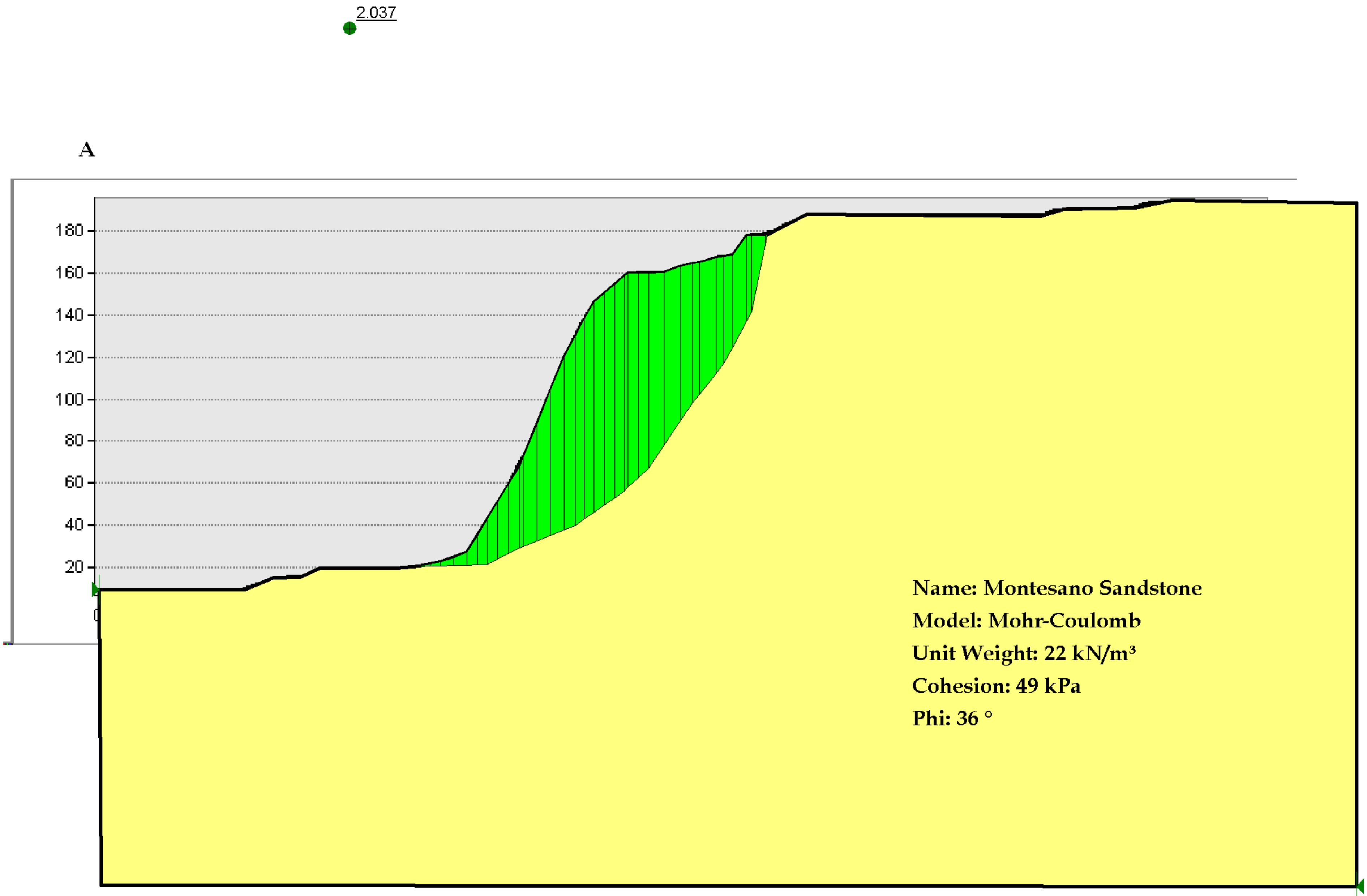

With an acceleration of .4 g, FOS goes to 1.1

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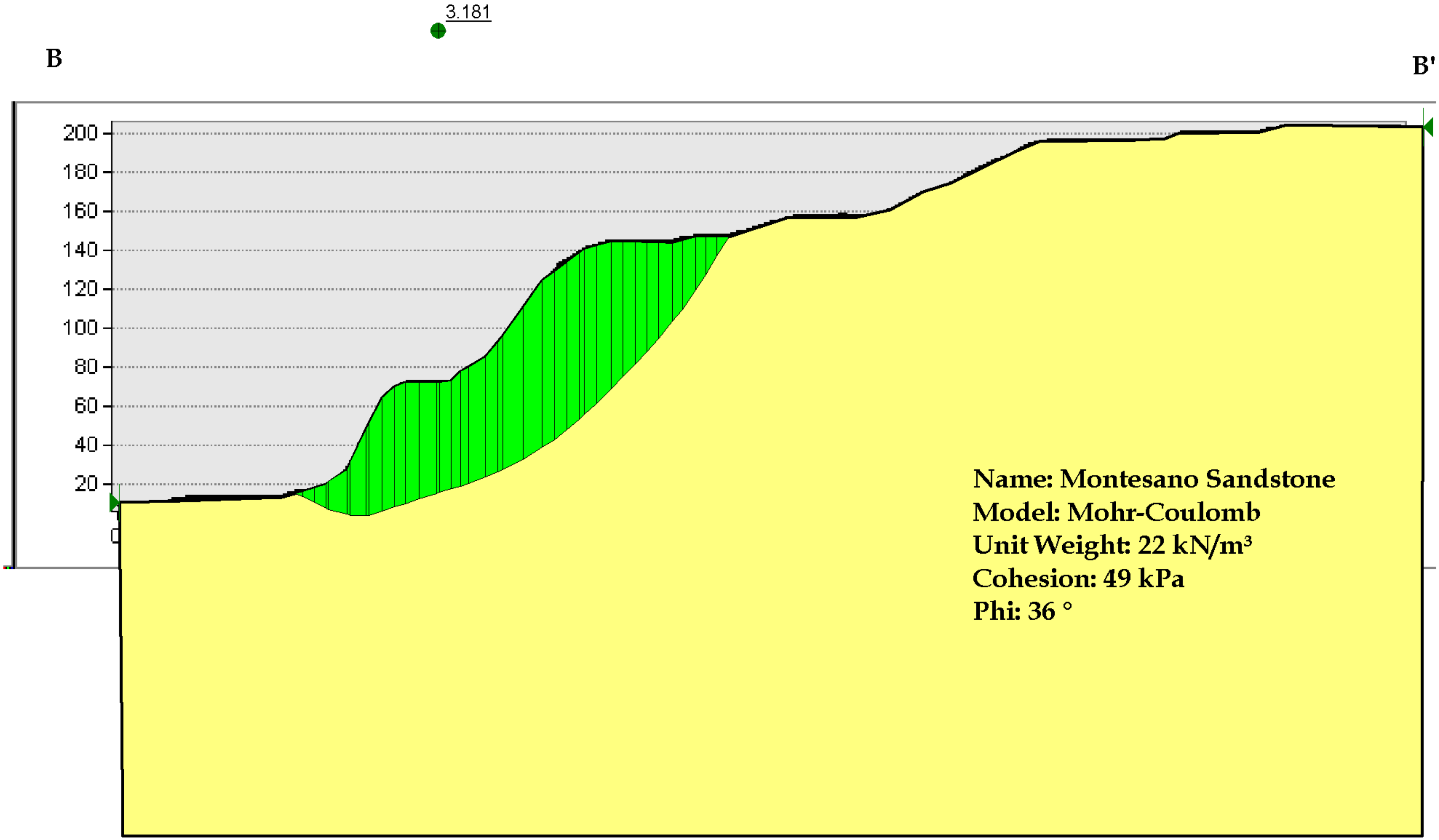

With an acceleration of .4 g, FOS goes to 1.57

Pros and cons

- Quick regional analysis
- Utilizes regional information

- However,
  – Doesn't take into account bedrock jointing or heterogeneous strength characteristics

Good first order analysis to inform and prepare officials and citizens!

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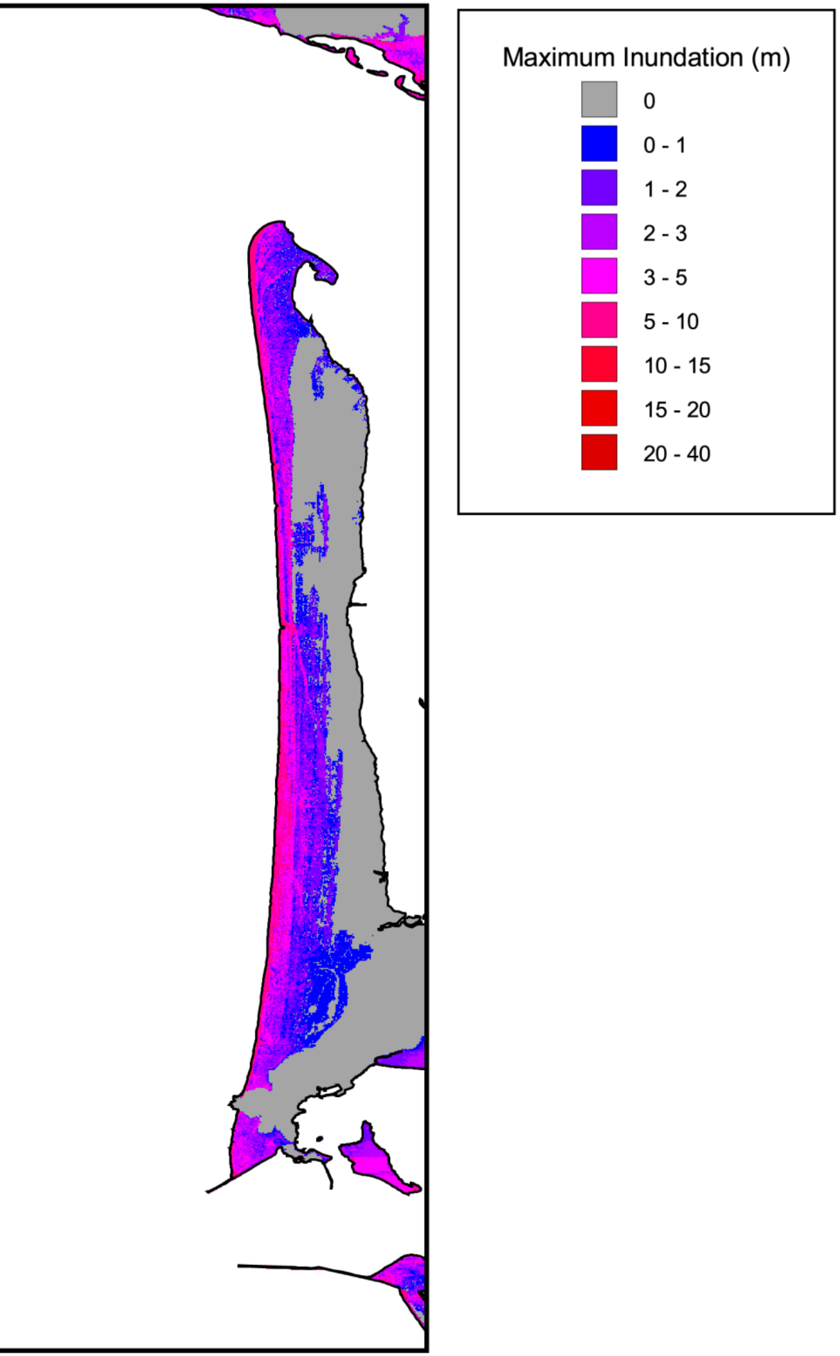
Bruceport
101
Willapa Bay
101
Willapa National Wildlife Refuge
101
Long Beach
101

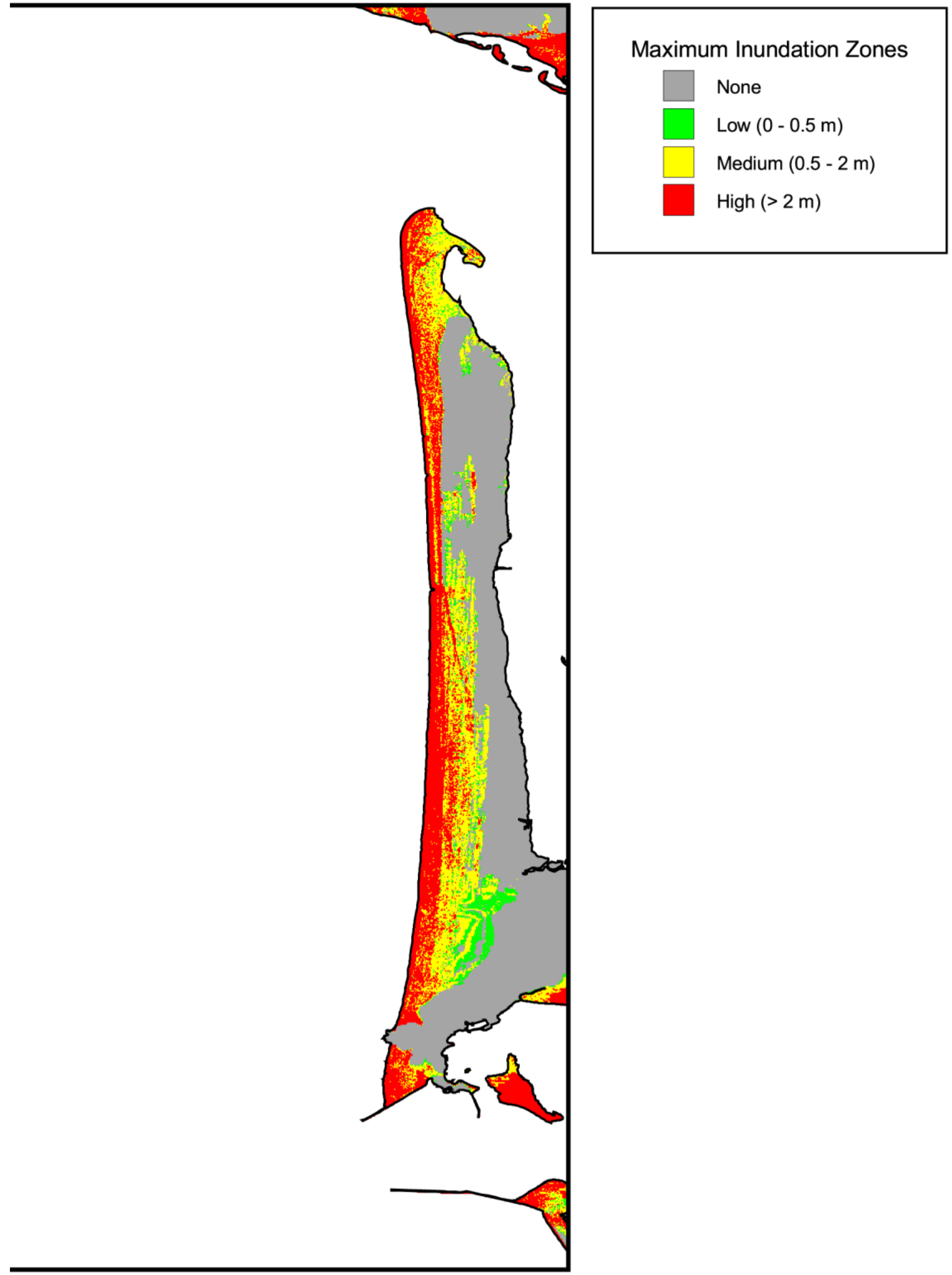

②
3
Long Beach
①
Seaview
Ilwaco
2
1
Cape Disappointment


Leadbetter Point
Oysterville
Ocean Park
③

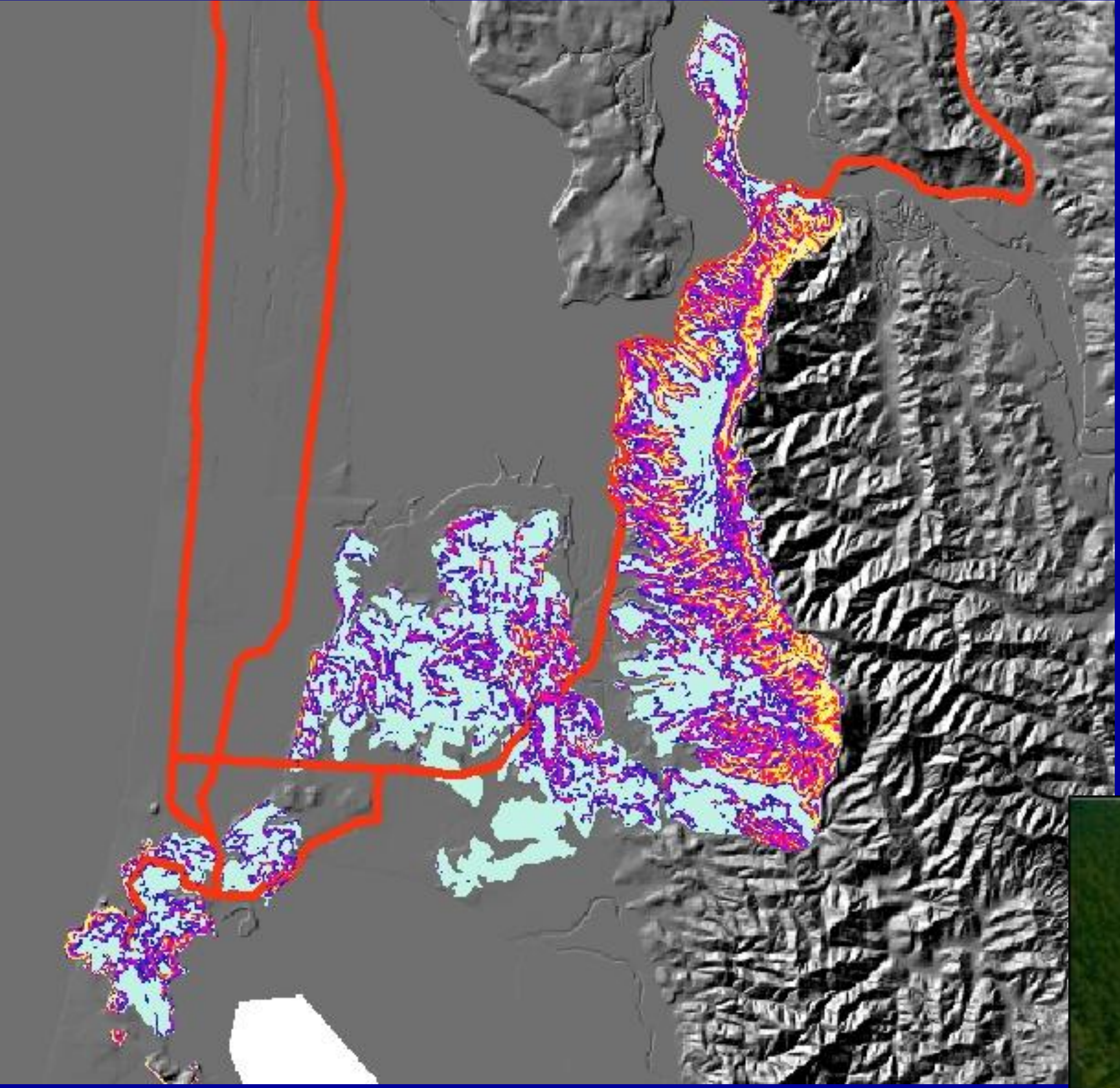
Washington - Modeling Results



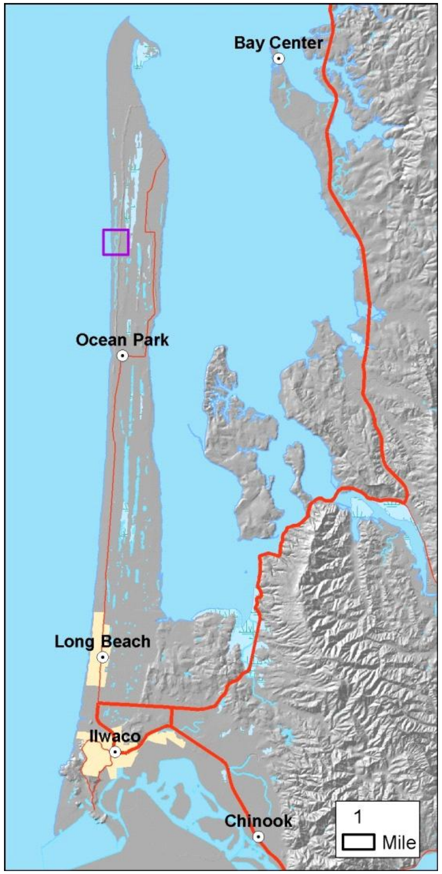
ong Beach, Washington - Modeling Results



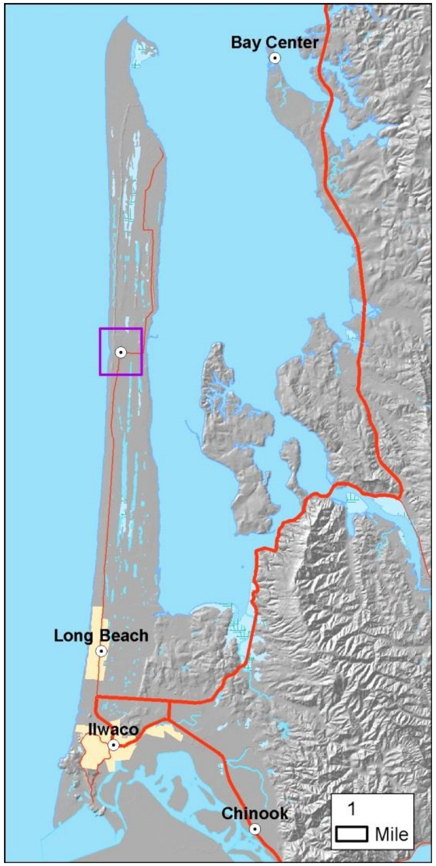
Critical acceleration



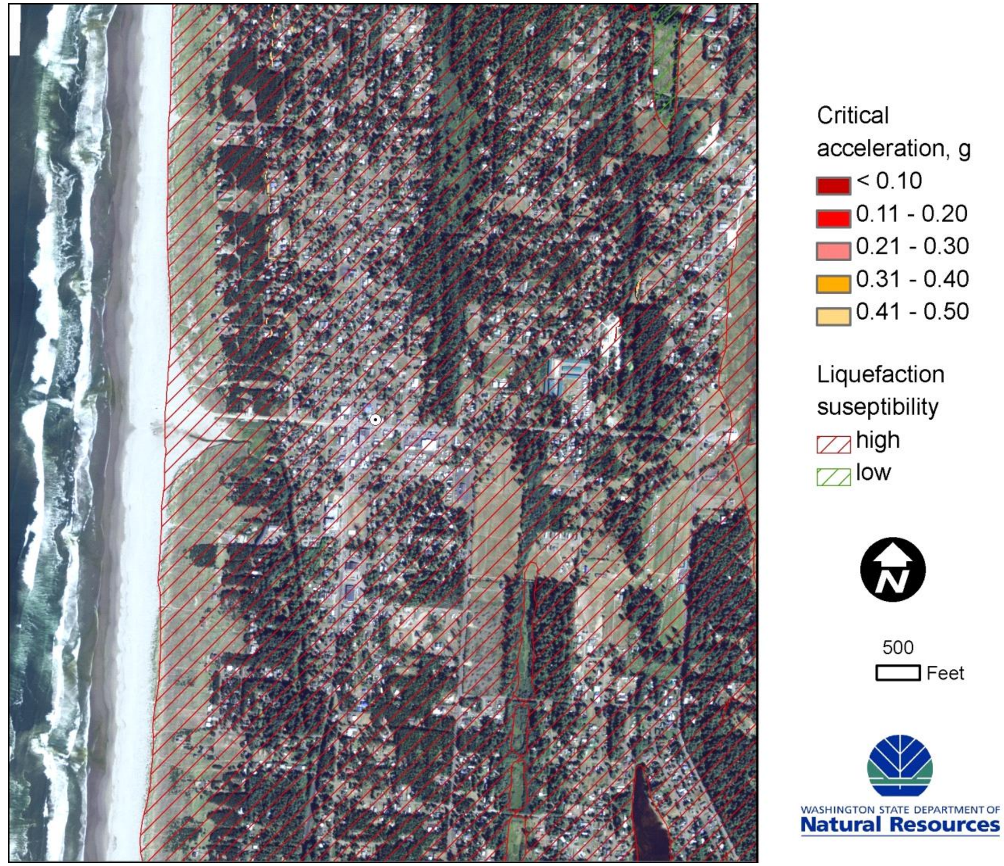
Oysterville Road



Ocean Park



Bay Center
Long Beach
Ilwaco
Chinook
1
Mile



Critical acceleration, g
< 0.10
0.11 - 0.20
0.21 - 0.30
0.31 - 0.40
0.41 - 0.50
Liquefaction susceptibility
high
low
N
500
Feet
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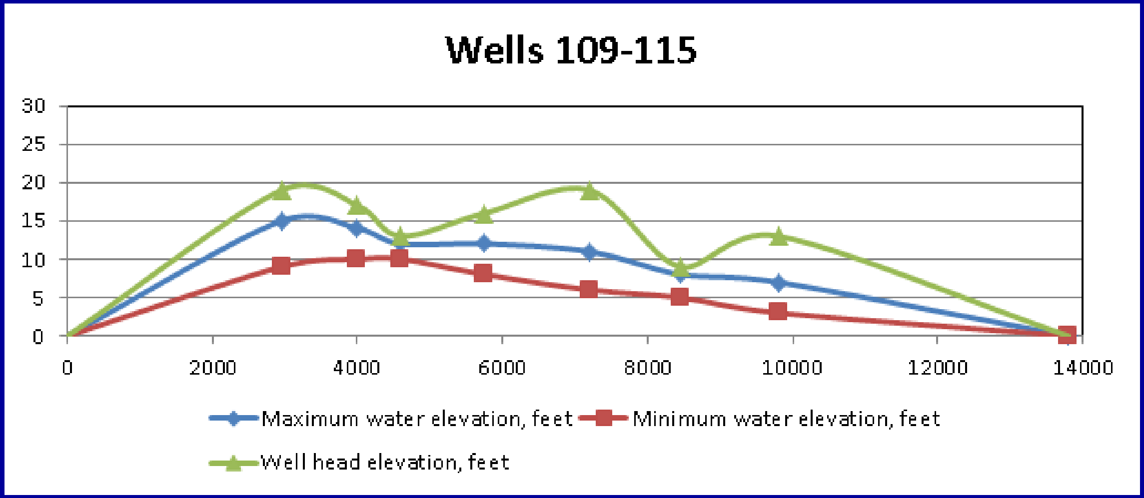

Figure XX. Cross-section showing well head elevation and minimum and maximum groundwater elevation levels recorded from monitoring wells between 1992 and 1993. X-axis values at 0 and ~14,000 feet represent the shoreline. 90x vertical exaggeration. Facing north. Values from Heath (1983). Average maximum depth to water table is ~12 ft in the lowland. Virtually no geotechnical data are available.

Thank you!

Knowing the vulnerability in the tsunami hazard zone can inform the placement of signs such as this